A Study on the Gas Sensor of AlGaN/GaN Schottky Diode with Surface Defect

1Minjun Kim, 1Seungmo Kim, 1Gyoutae Park, 1Byungduk Kim, 1Youngdo Jo and 1Yeonjae Lee
1Institute of Gas Safety R&D, Korea Gas Safety Corporation, Chungcheongbuk-do, Republic of Korea

Abstract—AlGaN/GaN devices have received a considerable amount of attention in relation to high-power applications due to their wide band gap properties. To achieve control of the leakage current using a cap layer addition, various surface treatment methods and results were discussed. However, the influence of different capping layers on material properties and transistor performance has not been investigated so far. We investigated the effects of various capping layers, such as n-GaN and u-GaN formed on AlGaNGaN Schottky diodes, on the performance of devices using TLM(Transfer Length Method) and AFM(Atomic Force Microscope) analysis. Also we studied impendence changes of Schottky diodes by injecting gases with diverse concentrations.

Keywords—AlGaN/GaN; AFM, cap layer; dislocation; GaN; gas sensor; Schottky; TLM;

I. INTRODUCTION

Typical diodes have characteristics such as rectification, detection, constant voltage, constant current, light emission, switching by junction of a p-type semiconductor and an n-type semiconductor. However, Schottky diodes create a barrier through the junction of the metal and the semiconductor. Therefore, the turn-on voltage is lower than the PN junction, and the recovery time is short when the bias is switched, thus enabling high-speed switching[1]. Since the existing Si-based semi-conductor is a physical limit has come, making the Si instead, the importance of the development of the next generation semiconductor materials are highlighted. Recent GaN-based semiconductors, there is a merit of excellent thermal stability and wide band gap(3.4eV), it has attracted a lot of attention of the next generation of power devices[2]. When AlGaN is grown on GaN and used as a heterojunction, a two-dimensional electron gas(2DEG) with high charge density is formed at the interface due to the polarization of AlGaN/GaN. This can obtain good device characteristics than when used alone GaN[3]. Despite the advantages, reduction in instability and reliability of operation of the various electrical defects, there is a need for improved. Especially GaN wafer is difficult to large diameter in a bulk state, threading dislocations generated during the growth of the substrate is reported primarily due to drop the reliability[4][5][6][7]. On the other hand, graphene is a thin film type nanomaterial in which carbon atoms are arranged in a honeycomb-like shape, and is used in various fields because of its excellent conductivity, transparency and flexibility [8]. Thus, in this experiment, the cause of the reduction characteristics of GaN based devices were analyzed using atomic force microscope and transfer length method. In addition, a Schottky diode consisting of a heterojunction of graphene and Silicon or AlGaN has been proposed as a potential gas sensor for a variety of combustible gases.

II. EXPERIMENTAL DETAILS

AlGaN/GaN heterojunction devices are grown mainly on SiC, Si and Sapphire substrates by MOCVD(metal organic chemical vapor deposition) according to crystal orientation. In this experiment, current leakage characteristics of the device according to the cap layer were compared using a GaN buffer layer for minimizing lattice mismatch, a GaN layer containing almost no impurities, an AlN intermediate layer of 1nm or less, and an AlGaN layer of 20~30% Al mole fraction are grown on a sapphire substrate. The substrates used for comparison were three substrates each having a non-capping(without) layer, a Si doped GaN layer and a non-doped GaN capping layer.

For electrode formation, each sample was immersed in acetone, methanol, and DI(deionized) water, washed for 5minutes each, and photo-lithography was performed to form a photo-resist patterns of TLM and ohmic contact. Then, Ti/Al/Ni/Au was deposited for ohmic contact with thickness of 20/120/40/50nm using an E-beam evaporator and lifted off with ethanol. For low resistance of ohmic junction, the RTA(rapid thermal annealing) process was performed at 950℃ in a nitrogen ambient for 45 seconds. Ni/Au was deposited to a thickness of 50/200nm by the same process as ohmic contact. The diameter of the Schottky junction to be used for the experiment is 100μm, and the ohmic junction is surrounded by a circular ring and it is 50μm away from the Schottky junction.

III. RESULTS AND DISCUSSION

A. Properties of ohmic junction

A TLM analysis method was used to compare the ohmic contact characteristics by the cap layer. The structure of the TLM pattern is obtained by arranging six 150×100μm² size rectangles at intervals of 4, 8, 16, 32, 64μm. Current-voltage measurements were obtained with a Keithley 2400 Source Meter 2400. Transmission length(LT), contact resistance(RC) and resistivity(ρ) of each device were calculated and shown in Table 1.

Table 1: LT, RC, ρ Of Derived From TLM Analysis

<table>
<thead>
<tr>
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<th>LT(μm)</th>
<th>RC(Q)</th>
<th>ρ(Ω·cm²)</th>
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</thead>
<tbody>
<tr>
<td>Without</td>
<td>45.52</td>
<td>141.97</td>
<td>5.01×10⁴</td>
</tr>
<tr>
<td>n-GaN</td>
<td>15.73</td>
<td>27.21</td>
<td>2.59×10⁴</td>
</tr>
<tr>
<td>u-GaN</td>
<td>13.71</td>
<td>33.53</td>
<td>3.66×10⁴</td>
</tr>
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</table>

In the TLM analysis, resistivity of without, n-GaN and u-GaN according to the capping layer was calculated as 5.01×10⁴, 2.59×10⁴, and 3.66×10⁴Ω·cm², respectively. The reason for the low resistivity of the devices with the capping layer is that the concentration of 2DEG in the AlGaN/GaN interface was lowered during the growth of the capping layer on the surface, and thus the electron mobility is increased because the scattering effect is reduced [9].

B. Properties of Schottky junction

![Image](a)
We also used Keithley 2400 Source Meter for the current-voltage characteristics of AlGaN/GaN Schottky diodes. The measured characteristic data are shown in Fig.3 as a linear scale and a log scale graph.

The Schottky diode with n-GaN cap layer, which had a low resistivity, showed the best on-resistance when a forward biased. On the other hand, the reverse leakage current of the Schottky diode with n-GaN cap layer was measured to be $10^6$~$10^7$ times greater than the other two devices when measured at -10V.

The reverse leakage current characteristics of the AlGaN/GaN Schottky diodes and the surface dislocation density tend to be almost identical in Fig. 5. This is because the Si film is doped at a high temperature in the process of growing the n-GaN cap layer on the AlGaN/GaN epitaxial structure, the surface film quality of the substrate is lowered, the surface level is generated due to deterioration of the film quality, so that the leakage current is estimated to be increased [10].
Fig. 6 shows the mechanism for detecting gas molecules using graphene. When defect-less graphene is placed on a defective substrate, it behaves like a defective graphene. In other words, defective graphene is very sensitive and can be used to make gas and chemical sensors due to minute resistance change when gas molecules are adsorbed. Graphene, such as a two-dimensional sheet of carbon atoms arranged in a honeycomb lattice, can detect each gas molecule adsorbed on its surface due to a high surface area of about 2600m²/g. In addition, the high mobility of charge carriers in graphene can vary between about 2500 and 4000cm²/Vs, which means that it can detect a greater number of chemicals and biomarkers as compared to other solid materials [11]. As shown in Fig. 7, we have designed a semiconductor device that enables a Schottky diode to effectively transmit a minute current to a small resistance change by adding a graphene layer on the AlGaN/GaN epitaxial structure [12].

CONCLUSION

In this study, we fabricated Schottky diodes using different cap layer on the AlGaN/GaN epitaxial structure, and compared the characteristics of ohmic junctions by TLM method. And the relationship between the leakage current of the devices and the surface state was confirmed through the I-V measurement and the AFM image.

For the device with n-GaN cap layer, the resistivity was low but the reverse leakage current was about 10⁶~10⁷ larger than that of the other two devices. It is confirmed that the leakage current increases due to the increase of the surface state due to the deterioration during the n-GaN growth process through the AFM image.

Since the film quality of the AlGaN/GaN substrate has a large influence on the leakage current, it is hoped that this will help to optimize the Schottky junction in future research on AlGaN/GaN-based electronic devices such as HFETs and HEMTs. In addition, the structural characteristics of the material suggested the possibility that the Schottky diode, which is formed by heterogeneous bonding of AlGaN substrate and graphene, which has poor film quality during epitaxial growth, can be used as a gas sensor for measuring volatile or combustible gas. And it is suggested that the Schottky diode fabricated by heterojunction of AlGaN substrate and graphene, which has poor film quality during epitaxial growth, can be used as a gas sensor for measuring volatile or combustible gas.

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References